Ultrasound computed tomography (Item No.: P5161200)

Curricular Relevance

Area of Expertise: Applied Sciences Engineering → **Education Level:** University → **Topic:** Non-Destructive Testing (NDA) → **Subtopic:** Ultrasounds → **Experiment:** Ultrasound computed tomography

Difficulty	Preparation Time	Execution Time	Recommended Group Size
Difficult	20 Minutes	2 Hours	2 Students

Additional Requirements:

- PC (Windows)

Experiment Variations:

Keywords:

Ultrasonic echography, A-scan, Tomography, Resolution

Overview

Principle

This experiment explains the fundamental principles of the image formation with a CT algorithm. A simple test object is used to create an attenuation tomogram and a time-of-flight tomogram followed by a discussion of the respective differences.

Caution!

Pay close attention to the special operation and safety instructions in the user manuals of the ultrasonic echoscope and CT scanner.

Fig. 1: Equipment for ultrasound computed tomography, experimental set-up

Equipment

Position No.	Material	Order No.	Quantity
1	Basic Set Ultrasonic echoscope II	13924-99	1
2	Extension Set: CT Scanner II, for 13924-99	13925-99	1

Tasks

1. Creation of several attenuation and time-of-flight tomograms
2. Variation of the device parameters
3. Discussion of the differences

Set-up and procedure

- Fill the tank with water. The water level in the tank should exceed the two transducer holders on both sides of the tank by at least 5 cm.
- Position the mechanical CT-scanner system above the tank as shown in Figure 1.
- Clean the transducer holders on both sides of the tank in order to ensure that there is no foreign matter (e.g. old gel residues) between the transducers and the tank.
- Apply a pea-sized quantity of gel to the centre of the probe surface and attach the two 2-MHz-probes to the transducer holders. Move the probe back and forth in order to distribute the gel evenly on the probe surface. If one looks at the contact surface between the transducer and the tank from inside the tank, the quality of the coupling layer can be assessed. Ensure that no air is trapped in this coupling layer, since this would reduce the sound that enters the tank (or the sound that travels out of the tank towards the transducer on the receiver side).
- Prepare the echoscope and the CT-scanner (read the manual of the echoscope and CT-scanner).
- Connect the CT-scanner to the drive unit. Use the buttons "Rotation" and "Translation" in order to test whether the scanner can be controlled with the control unit (the carriage moves and/or the sample holder rotates).
- Set the selector switch of the echoscope to "Transmission".
- Connect one of the two 2-MHz-probes to the "Probe (Reflection)" port and the other one to the "Probe (Transmission)" port.
- Connect the echoscope and the CT-scanner to the PC. Start the "measure Ultra Echo" software and select the CT-mode.
- Adjust the "Gain" and "Output" of the echoscope so that the signal that is displayed on the PC does not overshoot. TGC will not be used.
- Optimise the signal amplitude by slightly turning the transducers. Once you have found the optimum position of the transducers, fix them in place with the aid of the screws on their respective holders.
- Attach the test object to the carriage of the scanner. It will adhere by way of magnetism. Adjust the height of the scanner carriage so that the centre of the sample is level with the transducers. The scanner must be aligned so that the test object moves lengthwise in the middle of the tank. As of this point, the system should be controlled with the aid of the software.
- Set the echoscope "Gain" to 35 dB and the "Output" to 30 dB. TGC will not be used. The CT algorithm processes information from various different measurement depths. If the gain varies in different depths, the algorithm cannot work. This is why the TGC must be constant over the entire measuring range (0-200 µs), e.g. 0 in order to keep things simple.
- Since the sound is reflected on the tank walls, this reflected sound, which originates from the previous impulse, also reaches the receiver. This will result in an additional peak in the A-scan image, prior to the actual reception signal. However, this can only be seen if the test object is not located between the transducers since, otherwise, the attenuation in the object would be too high. If you notice such an additional peak, reduce the "Gain" and "Output" values until the peak disappears. (This additional peak does not affect the attenuation measurement but if it occurs prior to the actual measurement signal, it will distort the time-of-flight measurement. The CT algorithm will interpret this peak as a higher sound velocity in the test object and it will, therefore, compute incorrect images).

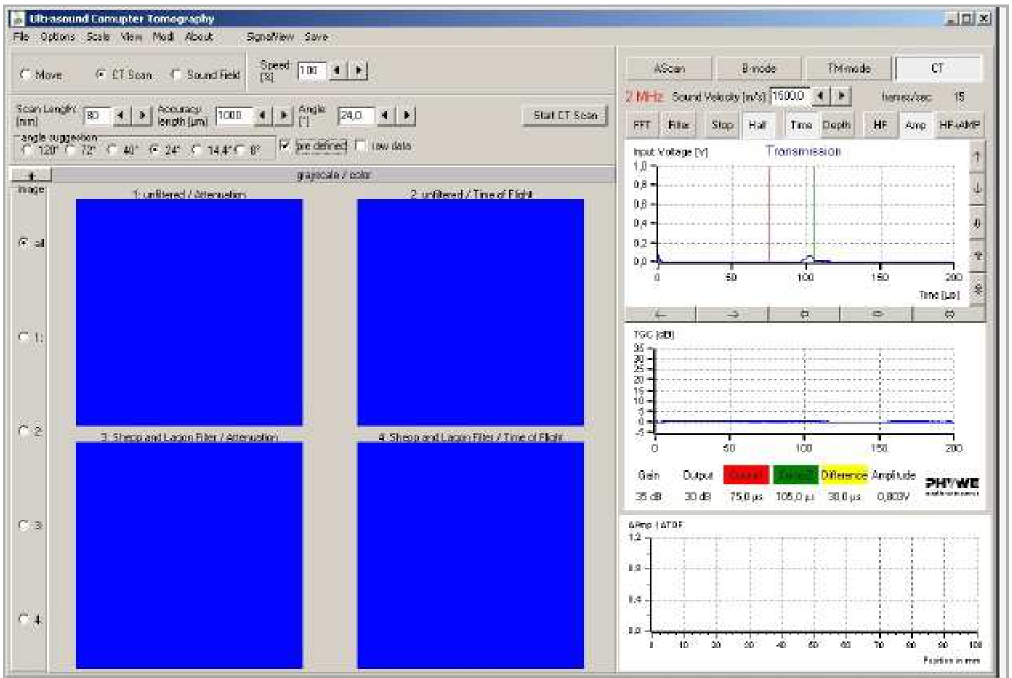

Fig. 2: Software: input of the CT-scan parameters

- Move the test object precisely to the middle between the two transducers. In addition to the actual "CT Scan" selection, the CT mode of the software also offers the option "Move" (in the upper left-hand corner). This option enables you to control the scanner without actually starting a measurement. The middle position is the starting point for all of the measurements.

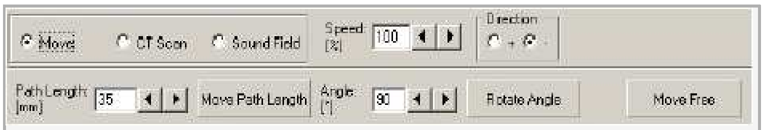

Fig. 3: Software: parameters for moving the scanner

- Determine the path length. It should be configured so that the measurement starts before the object and stops behind it. At the end points, the sound should only be affected by water and not by the CT sample. Enter "10 mm" into the "Path Length" field and move the carriage by clicking the "Move Path Length" button stepwise by 10 mm in a direction until the amplitude signal remains constant. Since, in the beginning, the sample was in the middle between the transducers, the path must be multiplied by 2 in order to also cover the other side of the measurement range. (Normally, 80 mm are sufficient for the path length. If the value is too high, the resulting image will be too small and the resolution will be affected negatively. If, on the other hand, the path length value is too small, the system cannot scan the entire object, which may lead to edge artefacts in the CT scan.)

- Select the parameter "Accuracy length", i.e. the distance (in µm) between two measurement points. The smaller the "Accuracy length" value, the more measurement points will be included in the measurement. (One has to bear in mind, however, that if a large number of points are covered, the carriage may move more slowly and it might be necessary to reduce the speed.)
- Enter the parameter "Angle". This value corresponds to the angular change between two scans. The measurements will be repeated until 360° are reached or exceeded. Note: Small angle values will increase the total measurement time, but they will not automatically improve the resolution, since there might be superpositions between the 1st and 3rd quadrant and also between the 2nd and 4th quadrant. The selection list offers several optimised angles.

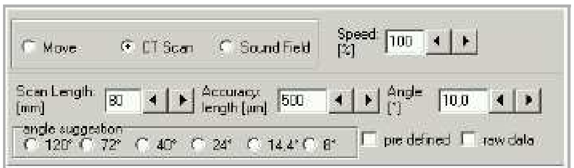

Fig. 4: Software: CT scan parameters

- Prior to every measurement, check the signal amplitude in order to ensure that it does not overshoot. To do so, move the carriage of the scanner sideways until the test object leaves the sound field. Then, the output and gain values are adjusted so that the amplitude signal (blue line in the A-scan) does not overshoot. The maximum of the blue line should be <=1. After that, the carriage must be moved back to the start position and the measurement must be restarted.
- Determine the influence of the device parameters on the images. For this purpose, the images do not need to be produced with the highest resolution. High values for the parameters "Angle" and "Accuracy length" reduce the measuring time. Start 4 measurements with the following parameter sets: path length 70 mm, accuracy 500 µm, angle 14.4°
- Output 20 dB, gain 25 dB
- Output 30 dB, gain 30 dB,
- Output 30 dB, gain 35 dB
- Output 30 dB, gain 35 dB + 35 dB TGC
- The software will display 4 images. The upper two images are the unfiltered attenuation image and the unfiltered time-of-flight image. The lower two images are filtered during the image generation. After each measurement, the images can be saved for later comparison or further evaluation. To do so, select "Save Images" in the "Save" menu.

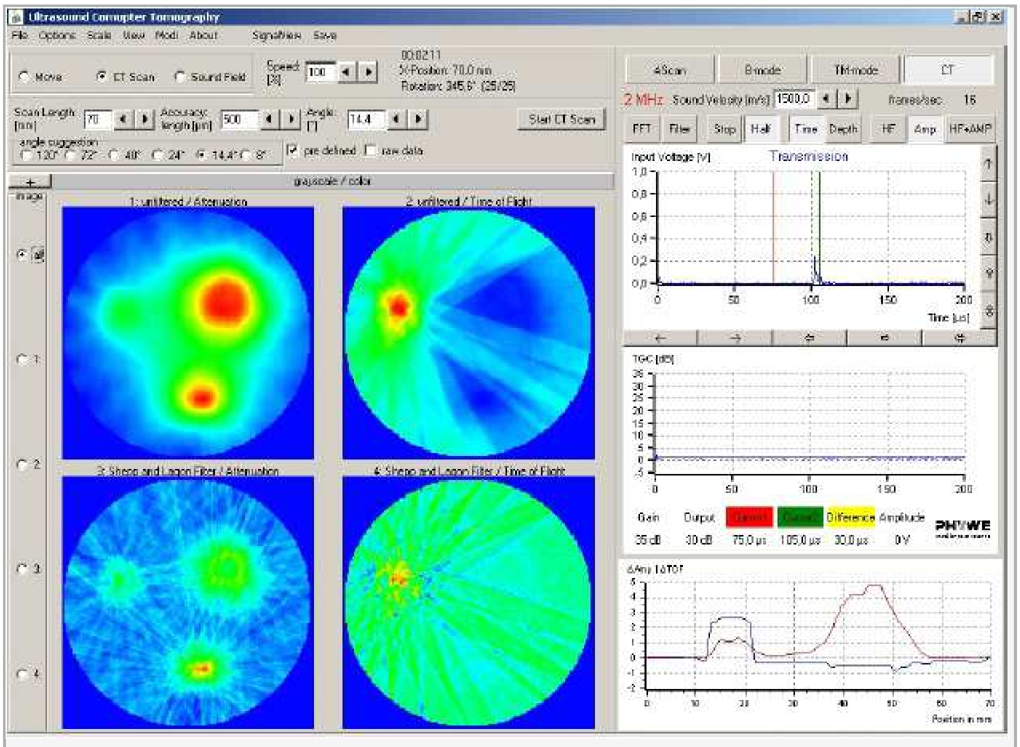

Fig. 5: Software: results of the scan

- Select the "Gain" and "Output" settings with the best result based on the previous measurements and then repeat the CT-scan with these settings and a higher resolution (angle <=14°, accuracy <500 µm).

Software

The "measure Ultra Echo" software records, displays, and evaluates the data that are transferred from the echoscope. After the start of the program, the measuring mode is active and the main screen "A-Scan mode" is displayed. All of the available actions and evaluations can be selected and started in this window.

For this experiment, the CT mode is used. In order to select it, click the "CT" button in the main window.

In the software, both status messages must be displayed in green (not in red) under "Options"/"Data Transfer". It is important that the CT scanner is also tested and controlled. The status can be refreshed by clicking the "Refresh Connections" button.

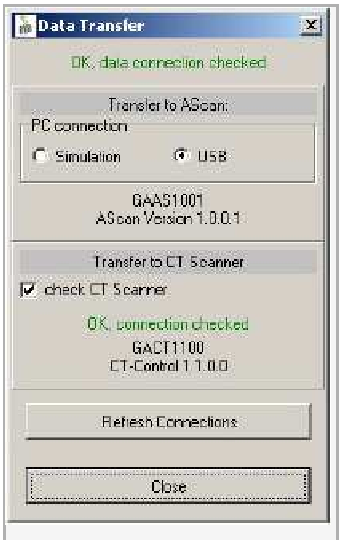

Fig. 6: Software connection

Note:

The ultrasonic probes and the probe holders should be cleaned immediately after use with water or a standard detergent. Dried residues of ultrasonic gel are difficult to remove. If necessary, use a soft brush. Never use alcohol or liquids with solvents to clean probes and holders. Deep surface scratches affect the coupling and can cause measurement errors.

Theory and evaluation

The X-ray computed tomography (CT) is one of the most important diagnostic methods in modern medicine. In addition, it can also be applied in industrial and research applications in order to obtain information concerning the inner structure of objects, which otherwise would have to be cut open and, thereby, be destroyed at least partially. One example that has been widely covered in the media is the examination of mummies in archaeology.

The traditional X-ray technology provides a two-dimensional shadow image of the three-dimensional object that is permeated by the radiation. In the image, the structures of various different layer depths of the object are superposed. This is why these images are also called superposition images.

The only difference between X-ray CT and ultrasound CT is the physical quantity that is evaluated. During X-ray CT, the attenuation/damping of the X-radiation is measured while it passes through the object, whereas during the ultrasound CT, the attenuation of the sound is measured. Apart from that, the algorithms for the evaluation are identical and even the resulting artefacts are comparable. In addition, ultrasound CT allows for the measurement of an additional quantity: the time-of-flight of the sound through the object and – derived from that – the sound velocity of the permeated object. The effort that would be required for doing this with X-radiation is not justifiable.

In this respect, the ultrasound tomography can provide additional information on an object since several parameters that have been measured simultaneously can be evaluated. The fact that the ultrasound tomography has gained less acceptance as a diagnostic method than the X-ray CT is due to that fact that it is more difficult to handle. In order to achieve an acceptable ultrasound transition from the transducer to the object (coupling), the patients would have to be placed in a water basin.

The following sections describe the process of a tomography measurement. The set-up of the US-CT that is described refers to the device that is used for practical training purposes. There are also US-CTs that have the same layout as X-ray CTs with a rotating scanner system.

During an X-ray CT, a transducer radiates through the object. The rays that are attenuated (damped) by the object are detected by a receiver in several places simultaneously. Then, the transducer/receiver system rotates around the object (i.e. the patient) and starts a new scan. This is repeated several times until all of the required angles have been covered.

The Phywe US-CT has only one receiver so that the damped intensity can only be measured only in one place at a time. This is why the attenuation values of the object must be measured one after the other in several different places. The distance between these measuring points stands for the accuracy, while the sum of all of the distances represents the scanning length. After such a scan, the object must be turned instead of the transducer/receiver system prior to starting the next scan.

Once all of these measurements are complete, one has all the information that is necessary for reconstructing the tomographic image. Normally, several tomographic images are produced during such an examination. The patient is moved lengthwise and the process is repeated. Then, the whole process is repeated until the entire area that is to be examined has been covered.

The following applies to the attenuation of a homogenous medium:

$$I = I_0 e^{-\mu x} \quad (1)$$

in which I is the intensity behind the object, I_0 the intensity without the object, μ the attenuation coefficient, an x the layer thickness.

When there is no homogenous medium left, it can be disintegrated into volume elements (voxels) with the same edge length Δx, which leads to:

$$I = I_0 e^{-\sum_i \mu_i \Delta x} \quad (2)$$

in which μ_i describes the individual volume elements if the sound passes through i layers. If one now transposes this equation and takes the logarithm, the following results:

$$\sum_i \mu_i = \frac{1}{\Delta x} \ln \frac{I_0}{I} \quad (3)$$

This is how an intensity profile can be converted into an attenuation profile of the individual scans. The attenuation profiles of the individual scans are superposed while taking into consideration the angles that were used. The result is a two-dimensional representation of the attenuation coefficients in the layers that were examined.

This simple superposition leads to extensive blurring of the details in an image. This is why the algorithms for the computed tomography apply a suitable filter function for a convolution in order to change the logarithmised attenuation profiles in a targeted manner prior to the superposition. The convoluted profiles have positive but also negative components. If the filter function is correct, these negative components just about eliminate the blurring effect.

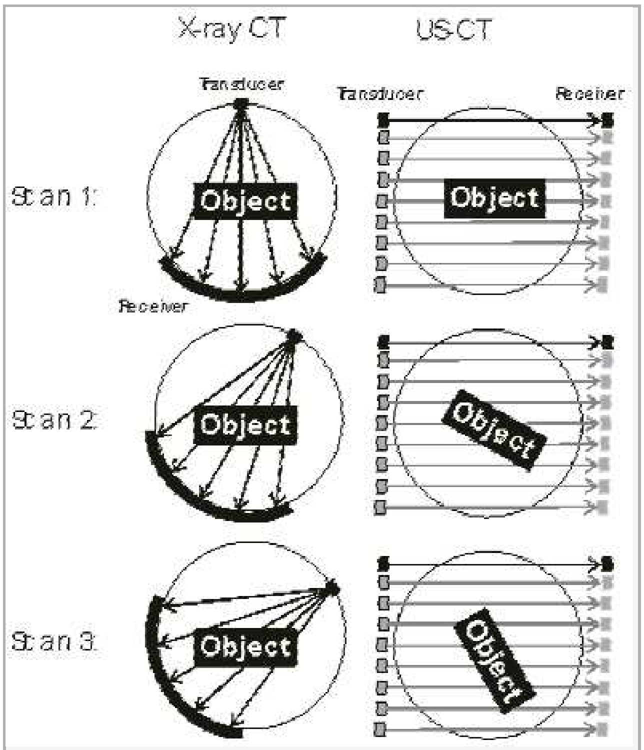

Fig. 7: Comparison of the scanning methods

As far as the selection of the angular increment is concerned, one must ensure that there is no superposition of the directions of the 1st and 3rd quadrant and of the 2nd and 4th quadrant. In addition, the angles between the various directions that are examined should be constant. If these criteria are followed in the 1st and 3rd as well as in the 2nd and 4th quadrant, the following results:

$$nx = 180^{\circ} + \frac{x}{2} \quad (4)$$

$$x = \frac{180^{\circ}}{n-1/2} \quad (5)$$

In the equations (4) and (5), *x* is the angular increment and *n* is an integer.

The rational solutions of this equation are listed in the following table.

Table 1: Rational solutions of equation (5)

n	*x*	*n*	*x*
1	360°	23	8°
2	120°	38	4.8°
3	72°	63	2.88°
5	40°	113	1.6°
8	24°	188	0.96°
13	14.4°		

Results

Figure 8 shows the changes in amplitude and sound velocity during the scanning process. Once a scan is completed, the profiles are integrated into the superposition image and displayed accordingly. As a result, the formation of the total image can be observed step by step from scan to scan.

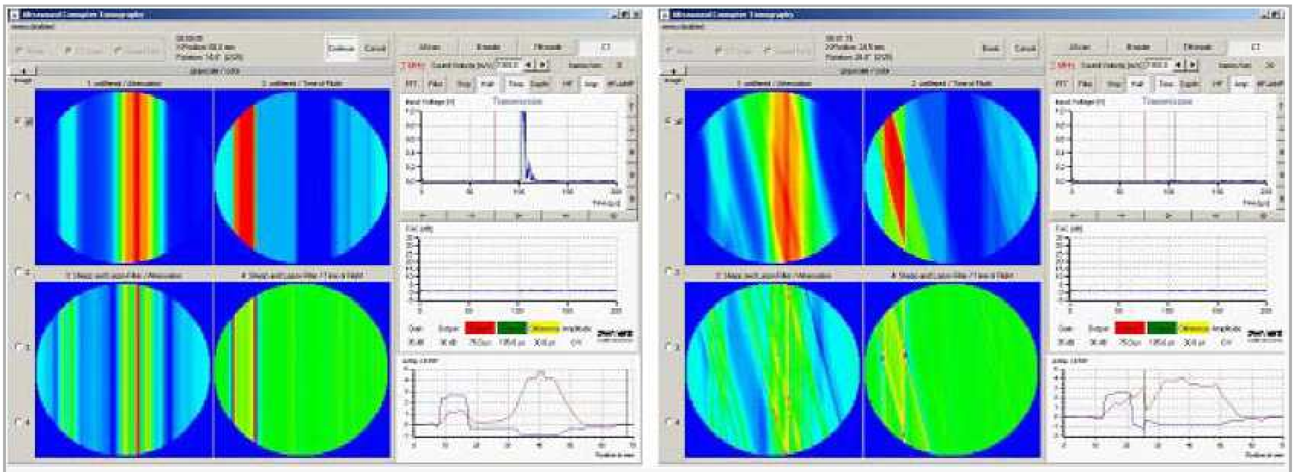

Fig. 8: Software: image formation after the 1st and 2nd scans

At first, the attenuation image shows two clear, circular structures (red). Following the variation of the contrast (under "Grayscale/Color") and also in the associated filtered image, one can see another structure on the left-hand side above the first two structures. The test object includes three rods, two of them with the same attenuation, but different diameters, and the third one with a very low attenuation close to the attenuation of the ambient material of the test object. The third rod, however, has a different sound velocity than the other two rods and also than the object material. As a result, the third rod can be clearly seen in the time-of-flight image, whereas the other two rods can be hardly distinguished from their environment.

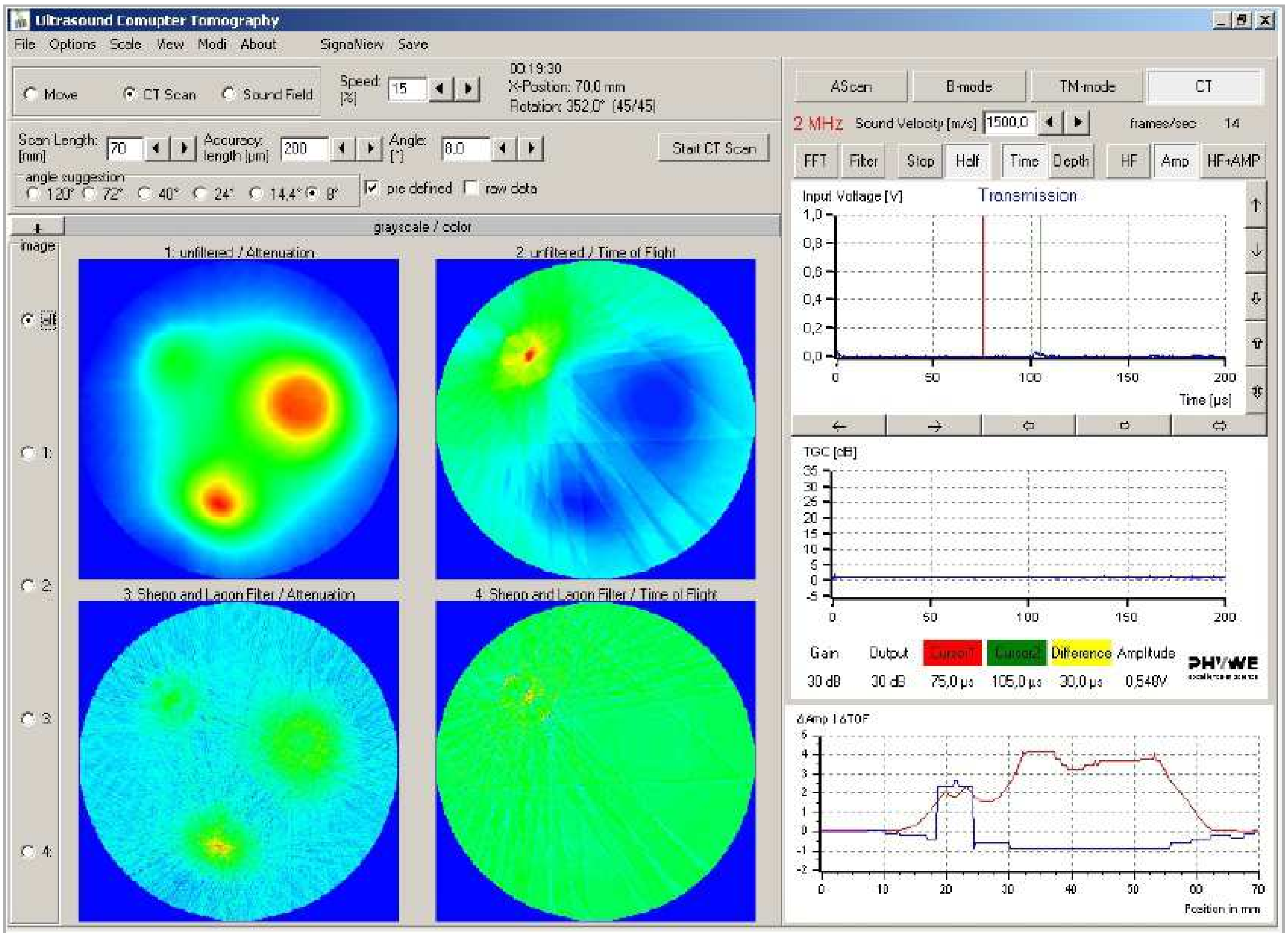

Fig. 9: CT-scan: output 30 dB, gain 30 dB, path length 70 mm, accuracy 200 µm, angle 8°

If one compares the filtered images to the unfiltered ones, it becomes clear that the filter has a positive effect only on the attenuation images where the transient areas are sharpened. In the time-of-flight images, on the other hand, the filter leads to a strong deterioration. This also applies to images with different gains. The Shepp-Logan filter that is used here is an edge-enhancing filter that is used quite often in X-ray CT applications. It shows that a supposedly helpful method does not improve the results in all of the cases, which is why it should always be questioned. (If one looks at the filtered time-of-flight image, one might come to the conclusion that the differences in sound velocity do not provide any information concerning the test object, but actually an unsuitable filter was used. In medical diagnosis, such an example could have severe consequences.)

Figure 10 shows the results for various different output and gain settings of the echoscope (in the fourth image, the TGC had been additionally activated over the entire measuring range of 0-200 µs, thus the additional 35 dB).

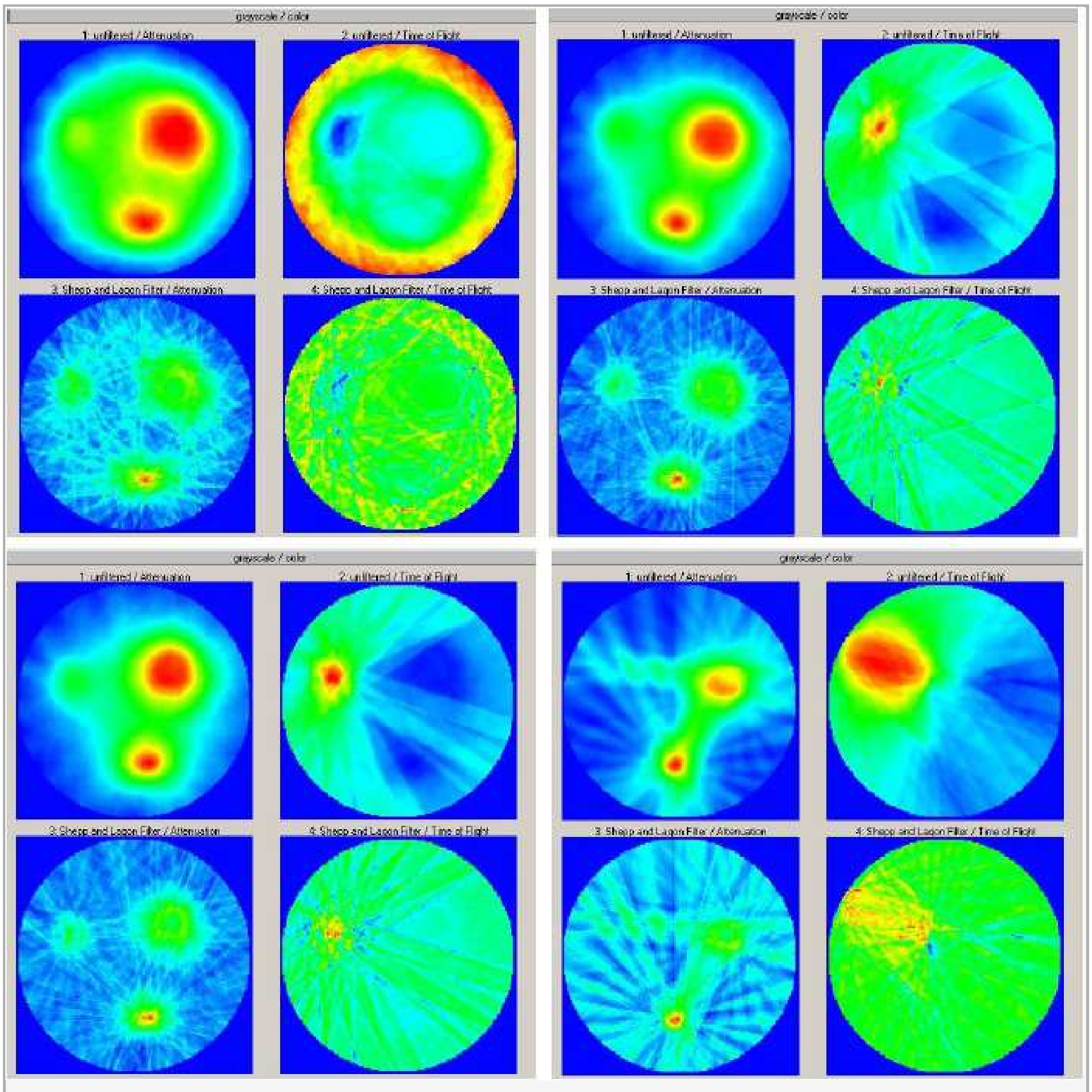

Fig. 10: CT-scan: path length 70 mm, accuracy 500 µm, angle 14.4°

a: output 20 dB, gain 25 dB
b: output 30 dB, gain 30 dB,
c: output 30 dB, gain 35 dB
d: output 30 dB, gain 35 dB + 35 dB TGC

The images show that with a low gain (10a) the transition of structures with small differences in attenuation can be displayed more clearly than with a high gain. In the first image, the round outer structure of the test object is clearly visible, which is no longer the case with higher gain values. This can be explained by the fact that, for the first image, the settings have been selected just so that the signal would not overshoot when it passed through the water. If it overshoots in this area, it is of course impossible to represent the structures of the transient areas. If the gain is too high, it may be possible that even higher attenuating objects, such as the third inner rod, cannot be represented clearly, even if the attenuation image is filtered (see also 10d).

On the other hand, the contrast of the third rod in the time-of-flight image increases when the gain increases. Since during the time-of-flight measurement the time that passes until a certain amplitude is reached is measured, the resolution improves during such a measurement with an increasing amplitude. (The maximum amplitude is of no interest in this context; the signal cannot overshoot.)

The images clearly show that the advantages of the US-CT are based on the combination of several measurement quantities (attenuation and time-of-flight). In our example, a signal that is too weak can be compensated by another signal and the observer can also obtain additional information from the images. (The fact that there are three rods included in the object can still be seen in the attenuation image, but the fact that the third rod is made of a different material is hardly discernible.)

The upper images are shown without a contrast correction. Some of the differences in the images, which are due to the different gain values, can be compensated for by a subsequent contrast correction. One should always try, however, to select the suitable device parameters prior to the measurement instead of correcting the images afterwards.